



ASIA **TURBOMACHINERY** & **PUMP** SYMPOSIUM  
12 - 15 MARCH 2018  
SUNTEC SINGAPORE

## The Selection and Design of Dual Pressurized Liquid Sealing Systems

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## ABSTRACT

Dual mechanical seals represent one of the most common approaches to improving seal reliability and reducing process emissions. While the presence of the pressurized barrier fluid provides significant benefits, the challenge for the end user is to select the most appropriate method of creating this pressurized environment. Fortunately there are several defined options for piping plans which describe the general characteristics of a dual pressurized sealing system. This however is just the starting point. The user must consider the impact of the seal design, the operating environment of the pump, and the considerations and risk assessment for upset conditions in their system evaluation. Other factors include maintenance requirements and seal monitoring strategies. Finally the selection of individual components for the systems will be dictated by operational requirements, local codes, and customer preferences. All of these considerations will require that the end user use a complete, systematic evaluation of their application in specifying the most appropriate system.

## INTRODUCTION

Mechanical seals are the most common method for sealing centrifugal pumps and many other types of rotating equipment. While there has been a significant amount of material published about general seal performance, there has been less material published on mechanical seal piping plans. Some of this information includes coverage of general piping plan descriptions but there is very little information on choosing the correct piping plan and understanding the implication of this selection on the design of the seal and operating characteristics of the sealing system. As dual seals become more common across industry, the requirement to select the correct plan has become more important. Although all of the dual pressurized piping plans serve a similar function, their differences can be significant in certain applications and can be the differences between a reliable seal and a bad actor.

### *Arrangement 3 seals*

Mechanical seals can be provided in a number of different configurations to suit the needs of specific pump application conditions and end user requirements. While there are informally many variations in seal designs, there are a number of standardized arrangements which are commonly used in industry. These arrangements are most notably defined in API 682 – Pumps – Shaft Sealing Systems for Centrifugal Pumps and are designated as Arrangement 1, 2, and 3. Each of these arrangements has specific features and performance



characteristics.

Arrangement 1 seals are defined as having one single per cartridge assembly. This has historically been known as a single seal. Arrangement 1 seals have been the dominant seal arrangement for many decades. This is due to its simplicity and reliability in most seal applications. Normal leakage past the single set of seal faces goes directly to the drain or to the atmosphere. Leakage during a seal failure can result in a significant loss on product into the environment around the seal.

Arrangement 2 seals contain two sets of seal faces with a cavity between the two seals maintained at a pressure less than the seal chamber pressure. This cavity contains a buffer fluid and is vented to a disposal or recovery system. Process fluid leakage past the inner seal is captured by the buffer fluid system resulting in very low emissions into the environment. Historically, this arrangement has also been known as a tandem seal or a dual unpressurized seal.

Arrangement 3 seals are defined as a seal assembly consisting of two seals. The cavity between the seals contains a barrier fluid which is maintained at a pressure greater than the seal chamber pressure. Historically, this seal has also been referred to as a double seal or a dual pressurized seal. This arrangement prevents the migration of process fluid into the barrier fluid thereby eliminating process leakage to the environment. While Arrangement 3 seals have been available for many decades, they are becoming more common as end user seek to reduce product emissions or are subjected to more stringent environmental regulations.

While it is easy to think of an Arrangement 3 as only the mechanical seal, it is actually part of a larger sealing system. This system contains the mechanical seal, barrier fluid, seal system accessories, instrumentation, external utilities, and interconnecting piping. Over time, the industry has developed a number of strategies for creating these systems which have been defined in standardized piping plans. While all of the Arrangement 3 piping plans create a pressurized barrier fluid environment between the seals, the methods for doing can be significantly different. This allows the end user to select the piping plan which is most appropriate for their specific service. It is therefore helpful for the end user to understand the various options and the implications of their piping plan selection for their application.

## DUAL PRESSURIZED LIQUID SEAL PIPING PLAN OPTIONS

There are a number of critical functions which must be performed by the seal support system. The definition of an Arrangement 3 seal requires that the barrier fluid cavity between the seals is maintained at a pressure greater than the seal chamber pressure at all times. Creating and maintaining this pressure differential is a critical function of the piping plan. In addition, the piping plan provides a means to control the temperature of the barrier fluid. In most applications the piping plan contains a seal cooler or heat exchanger to remove seal generated heat and/or heat soak from the process fluid as well as a means to circulate the barrier fluid through the system. The piping plan also maintains a volume of barrier fluid which is required to reduce the degradation of the fluid and provide make-up fluid for losses through normal seal leakage.

There are four standardized piping plans that provide the foundation for most pressurized liquid seal applications. The definitions for these plans have historically been documented in API 610 and, in more recent years, in API 682. Several additional options were introduced in API 682 Second Edition in 2002. While there are many variations of the actual seal system design, most fall under the definition of one of four plans. Generically, Plan 53s are systems which provide the circulation of the barrier fluid by means of a pumping device on the rotating components of the mechanical seal. There are three common methods for providing the pressurization for the system which are designated as Plan 53A, Plan 53B, and Plan 53C. In API 682, these plans are considered technically equivalent although the unique characteristics of each plan may make one of them more suitable for a specific application. Plan 54s also provide a pressurized barrier fluid for the seals but the circulation of the fluid is provided from an external means. There are significant variations in Plan 54 systems as described below.

### *Plan 53A*

The Plan 53A is historically the most common method used to pressurize dual pressurized liquid sealing systems. This plan provides an external barrier fluid which circulates from the seal to a reservoir and back to the seal. The barrier fluid is pressurized by means of an externally supplied pressurization gas. The most commonly used pressurization gas is nitrogen due its inertness and availability at most end user locations. The nitrogen is normally supplied from a nitrogen header in the plant and the pressure is regulated down to the required barrier fluid pressure at the reservoir. The performance of the mechanical seals is monitored by directly monitoring the liquid level of the barrier fluid in the reservoir.



One of the strengths of the Plan 53A is its simplicity. The requirements of the reservoir used in these systems are defined in API 682 although many end users have developed overlays to meet their unique needs. The instrumentation and pressure regulator are all commonly used components in the plant. The nitrogen supply infrastructure (and cooling water, if required) already exists in most locations. Finally, the pressure regulation method is relatively stable and simple to adjust. These features made this plan the default for most low duty applications for many years.

The use of a pressurization gas however creates a fundamental limitation for the system. The nitrogen is introduced into the top of the reservoir which creates a high pressure blanket on top of the barrier fluid. By controlling the pressure in the space, the user controls the entire system pressure. The direct contact of the high pressure gas, however, allows for the absorption of nitrogen into the barrier fluid. The amount of dissolved gas into the fluid is roughly proportional to the pressure of the gas in the reservoir. As the operating pressure in the reservoir increases, so does the amount of dissolved gas. When the barrier fluid migrates across the seal faces, the depressurization in the fluid film can allow these dissolved gases to come out of solution and negatively impact seal performance. For this reason, Plan 53A systems are commonly limited to approximately 10.3 barg (150 psig).

The dominant feature in a Plan 53A is the reservoir. The Plan 53A reservoir is a vessel typically fabricated from piping components with volumes ranging from about 10 – 75 liters (2 – 20 gallons). The reservoir itself is equipped with a sight glass to visually monitor the barrier fluid level and is instrumented with a level transmitter or level switches to allow for remote level monitoring. The reservoir also has instrumentation for monitoring the system pressure through a pressure transmitter or a pressure indicator and switch. Reservoirs may be provided with internal cooling coils to help regulate the barrier fluid temperature in operation.

#### Plan 53B

The Plan 53B was developed to address some of the limitations of the Plan 53A. Rather than pressurizing the barrier fluid from an external source, the Plan 53B pressurizes the fluid with a bladder accumulator. Since the pressurization gas is contained in the bladder and not in direct contact with the barrier fluid, there is no gas absorption or related performance issues. This allows the Plan 53B to operate at substantially higher pressures than a Plan 53A. This also allows the Plan 53B to operate in remote locations since it does not rely on pressurization gas from an external source.

The simple addition of the accumulator however has a profound effect on the way that a Plan 53B performs. The accumulator acts as the reservoir for the barrier fluid and provides that make-up fluid to compensate for losses of barrier fluid due to normal seal leakage. There is no direct method for visually monitoring the volume of liquid or gas in the accumulator. As fluid leaves the accumulator to supply the circulation loop, the gas filled bladder will expand which results in a drop in pressure in the bladder and the entire sealing system. This drop in pressure is monitored to provide an indication of the seal performance. The pressure in the system is also impacted by the ambient conditions and the system design.

The accumulator is arguably the most critical component in a Plan 53B system. The size of the accumulator will have a direct impact on the relationship between seal leakage and the barrier fluid pressure. The actual sizing of the accumulator requires a reasonable estimation of the seal leakage and the required maintenance intervals for adding additional barrier fluid. A small accumulator will result in higher system pressures and a higher refill frequency. For high pressure applications, large volume accumulators (or even multiple accumulators) may be required.

A Plan 53B also requires cooling to help regulate the barrier fluid temperature. This can be provided by either a liquid-cooled or air-cooled seal cooler. Liquid-cooled units provide the highest efficiency and can provide relatively stable operating temperatures since they are connected to the plant's cooling water system. Air-cooled units will have greater variations in the operating temperature of

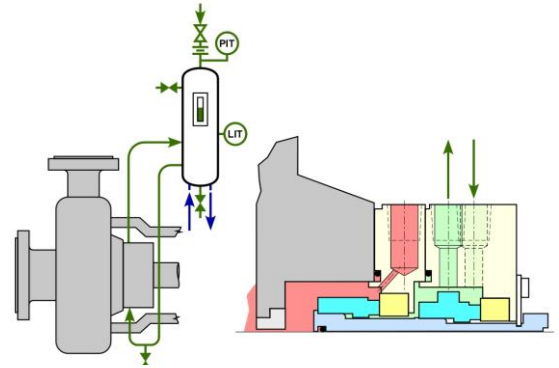


Figure 1. Piping Plan 53A

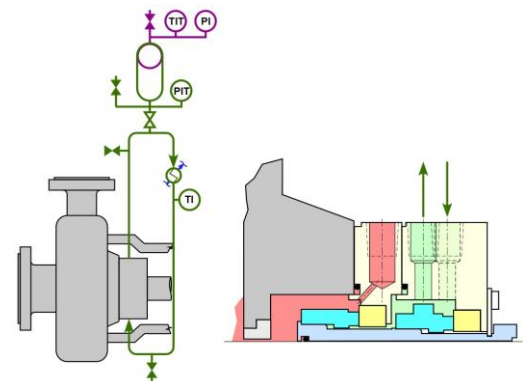


Figure 2. Plan 53B



the barrier fluid but they do not require a connection to an external utility such as cooling water. This makes them ideally suited for applications that are located in remote facilities or that do not have cooling water available.

#### Plan 53C

A Plan 53C represents an entirely different approach to pressurizing the barrier fluid. This uses the process fluid in the pump itself as the pressurization source. A piston accumulator (also called a piston transmitter) is designed to use the pressure in a reference line from the seal chamber to create a higher pressure in the barrier fluid. This is accomplished by designing the piston accumulator with differences in the hydraulically loaded areas on the low and high pressure side of the piston. The process fluid contacts the larger area on the bottom of the piston while the barrier fluid contacts the smaller area at the top resulting in a higher barrier fluid pressure. Most piston accumulators are designed with a ratio of areas ranging from about 1:1.1 to about 1:1.25.

There are some significant advantages to this approach. The pressurization source for the system is the process fluid in the pump itself. There is no need for an external pressure source. The barrier fluid is automatically pressurized as the pump is commissioned. This removes this step from the normal commissioning procedure. The barrier fluid pressure automatically tracks changes in the seal chamber pressure. This allows the Plan 53C to track not only normal variations in system pressure but also upset or other unexpected variations in the pump operation.

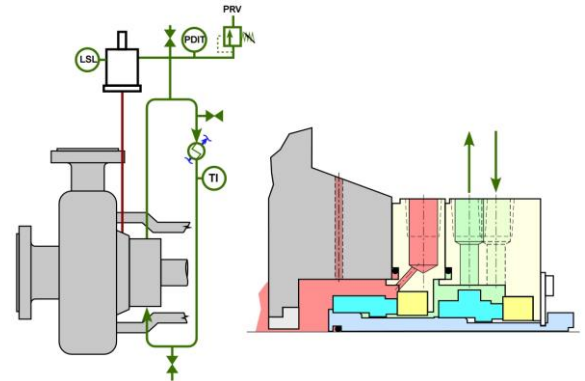


Figure 3. Plan 53C

The system is initially filled with barrier fluid and the piston moves into the “full position.” This is visually indicated by the having the rod which extends from the accumulator fully retracted. As barrier fluid leaks out of the system, the piston slides upwards and the rod extends farther out of the accumulator. In this way, the position of the rod is a direct indicator the volume of barrier fluid remaining in the accumulator and an indirect indicator of seal performance. When the rod reaches its maximum extension, the barrier fluid is at its lowest level and requires refilling by the operator. There are numerous methods of instrumenting the system to remotely monitor the piston position and indicate a low level in the system.

The piston accumulator unfortunately has some significant limitations. The Plan 53C is the only one the three Plan 53 options that has the process fluid in direct contact with the system components. The process fluid enters the accumulator through the reference line and energizes the barrier fluid through the sliding piston in the accumulator. This piston must remain free to move in operation. If the process fluid solidifies, plates out, deposits debris, or otherwise damages or degrades the walls of the piston transmitter, the piston will not slide and the system will fail. Damage to the dynamic seals on the piston will also allow the pressure to equalize on both sides of the system resulting in a failure. Since the accumulator is in direct contact with process fluid, all the materials of construction must be rated for continuous exposure to the process. Finally the weight of the piston itself and the drag of the dynamic gaskets can impact operation in low pressure applications. In general, it is recommended that this plan only be used in applications with barrier pressures greater than 7 bar (100 psi).

#### Plan 54

A Plan 54 is more of a definition of the function of the plan than is it an actual design or specification. A Plan 54 simply has the requirement to provide a pressurized barrier fluid from an external source. Like all of the Plan 53 options, the barrier fluid must be maintained at a pressure greater than the seal chamber pressure. The circulation of the barrier fluid is however provided by the Plan 54 and does not rely on the pumping action of the seal itself. This will provide circulation even when the pump is in standby conditions. Because the circulation pump can create pressures much greater than that developed by a pumping ring, more complex piping systems or seal designs than with the Plan 53 options. This can be a significant advantage in higher duty applications.

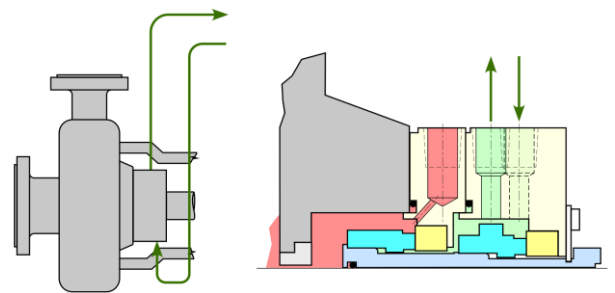


Figure 4. Plan 54

Since the Plan 54 has no formal definition, it is understandable that there is a significant spectrum of designs applied throughout industry. The designs used are a function of the application conditions, the





available utilities, the barrier fluid used, the number of seal supported by the system, and the end users expectations. Plan 54 systems however can be generically categorized as a process fluid system, a one-seal support system, and a multiple-seal support system.

#### *Plan 54 - Process Fluid Support System*

The selection of the barrier fluid is a critical step when considering the specifications for dual liquid seals. The barrier fluid has a number of requirements that must be met to ensure satisfactory seal reliability. Most dual liquid seal piping plan installations use barrier fluids that are either fluids formulated specifically as a barrier fluid or other fluids which have a large installed base of use as a barrier fluid. Some plants however have process fluids or utility streams which will function satisfactorily as a barrier fluid. These may be finished products produced by the plant, intermediate products with appropriate properties, or utility streams used within the plant.

If the source of the barrier fluid is at a pressure greater than the seal chamber pressure, a system can be designed to route the fluid from a high pressure header, through the seals, and back into a lower pressure header. This eliminates the need for an independent Plan 54 system, circulation pumps, or fluid reservoirs. The system is, of course, not necessarily this simple. The connecting system must control the pressure at the mechanical seals as well as monitor the barrier fluid pressure and flow rate.

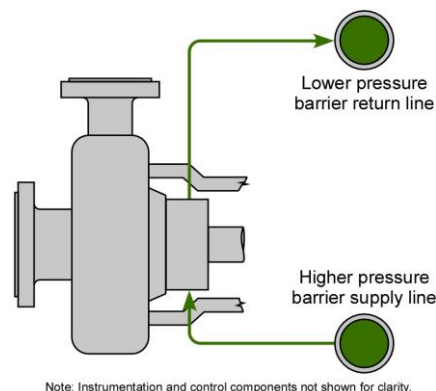


Figure 5. Plan 54 Process Fluid Support System

Using this option is relatively rare since it is rare to have all of the required elements of this system in the same location at a plant. There must be a high pressure header of a suitable barrier fluid and a low pressure header to capture it and reintroduce it back into the plant. The diversion of the barrier fluid between these two lines cannot be seen as a significant cost or lost opportunity within the plant. The reliability of the mechanical seal is now directly tied to the reliability of both of these process lines. These lines must both be available and at the correct pressures at all times while the seal is in service and there is process fluid in the pump. If the supply pressure of the barrier fluid is lost, it is possible that some process fluid can migrate into the low pressure leg. Finally, since the barrier fluid comes from a relatively endless source, a failure of the inner seal can result in excessive barrier fluid flow into the pump process that may be difficult to detect. Even with these limitations, there are locations that successfully use this option for a Plan 54 system.

#### *Plan 54 – One-seal Support System*

The most common design of a Plan 54 uses a small stand-alone system to support one mechanical seal. Double-ended pumps commonly have a separate system for each end of the pump. This Plan 54 system typically is designed as an open system with an atmospheric reservoir, a pressurization/circulation pump, a back pressure regulator, various fluid conditioning accessories, and instrumentation. While most seal OEMs have a number of standard models of these systems, they are highly modular and customizable for virtually any seal application.

As a support system for one seal, the components and performance can be tailored to the specific need of just that one seal. The barrier fluid used in this system can also be specific to this one application. Circulation is provided by a positive displacement pump. Due to the forced circulation, there is more flexibility in the location of the system relative to pump. Typical fluid conditioning is provided by an inline filter in the circulation line. Heat removal is provided by either a dedicated seal cooler or by cooling coils in the reservoir. These components are selected to support the needs of the specific application.

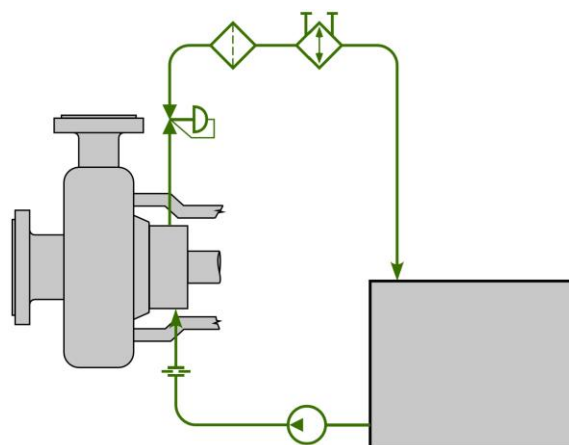


Figure 6. Plan 54 One-seal Support System

In an open system, the reservoir is at atmospheric pressure and is commonly fabricated from carbon steel or stainless steel plate. This allows barrier fluid to be added through an atmospheric connection at the top of the reservoir. The reservoir will commonly be provided with a visual site glass to monitor the barrier fluid level in the system. The reservoir will also be instrumented with a level transmitter or low level switch to remotely alert the operator of the need to add barrier fluid to the system. The level monitoring also serves as an indication of seal performance. Since only one seal is supported by the system, any drop in level can be attributed to the



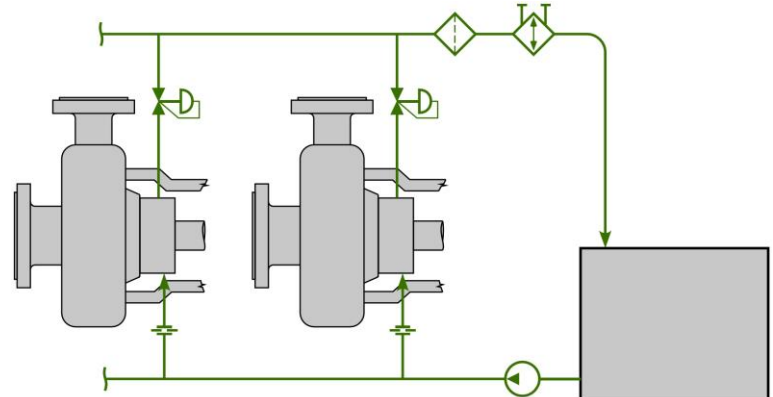
one supported seal.

Having a Plan 54 dedicated to only one seal also has the advantage of preventing a failure of either the seal or system on one end of the pump from affecting the seal on the other end. In the event of a failure of one mechanical seal, process fluid may contaminate the barrier fluid and support systems. A seal failure may also produce a small amount of debris related to the failure mode. These issues are isolated to only the effected seal and support system. It is relatively easy to flush these smaller systems during a seal change out if required.

#### *Plan 54 – Multiple-seal Support Systems*

As an alternative, Plan 54 systems can be designed to support more than just one mechanical seal. There is an obvious appeal to this approach on a between bearing pump with two mechanical seals. The entire pump is supported by a single Plan 54 system which can simplify commissioning and operating procedures. The same justification can be used to expand the system to include a spare pump or neighboring pump. This strategy has evolved to providing Plan 54 systems designed to support entire operating units in a plant.

Plan 54 support systems are engineered systems that can be scaled to support a relatively unlimited number of seals. The size of the reservoir, the flow capacity of the pressurization/circulation pump, and the size and number of the accessories in the systems are all variables which can be selected to support the needs of a multiple-seal system. As more seals are supported by the system, the reliability of the Plan 54 becomes more critical. Redundant equipment is provided for all major components. Multiple pressurization/circulation pumps are provided with automatic spares. Some systems are even designed with pneumatic driven back-up pumps in case of a loss in electrical power. Redundant filters and heat exchangers are also designed to allow for routine maintenance while the system is in operation.



Note: Instrumentation and redundancies not shown for clarity.

Figure 7 Plan 54 Multiple-seal Support System

This option for Plan 54 systems extends beyond the skid mounted unit itself. A high pressure supply header is piped from the Plan 54 skid to the area of the supported equipment. Individual, smaller supply lines are piped to each of the supported seals. Return lines leave the seal and join a lower pressure return header which feeds back into the system reservoir. Pressure and flow controls, along with appropriate instrumentation, are required in the system. The exact design and location of these controls depends upon the size of the system and the variations in operating conditions between the supported pumps.

The primary advantage to a multiple-seal Plan 54 is that it provides one location for controlling and maintaining the supported seals. There is only one fluid level to monitor, one location to add barrier fluid, one set of filters to change, and one system to commission prior to starting the plant. The level of engineering and redundancies in these systems can make them more reliable than smaller systems. There are trade-offs however. The entire system must use the same barrier fluid. Monitoring the performance of an individual seal can be difficult resulting in most end users primarily monitoring the aggregate leakage for all the seals in the system. Determining the leakage for a specific seal generally requires a manual intervention at the specific seal location. Creating specific barrier fluid pressure and flow rates for each seals requires careful engineering and can be challenging if there is a wide range of pressures required throughout the system. Even with these limitations, these systems are successfully used in plants worldwide.

#### *Comparison of Plan 53 and Plan 54 Options*

All of the options described about have installations in the field which are operating satisfactorily. This does not however imply that all of the systems are interchangeable. Each has unique characteristics that may make one more suitable for a specific application. Table 1 below compares some of the key features in each system.



Table 1 – Comparison of Key Features of Dual Liquid Seal Piping Plans

Plan	Plan 53A	Plan 53B	Plan 53C	Plan 54 Process Fluid	Plan 54 One-seal System	Plan 54 Multiple-seal System
Barrier pressure	Constant pressure	Variable	Constant ratio (1)	Constant	Constant	Constant
Pressurized by	External pressurization gas	Bladder accumulator	Seal chamber pressure	External supply source	Plan 54 system pump	Plan 54 system pump
Monitoring seal leakage	Level in reservoir	Pressure in system	Position of piston	Manual procedure	Level in reservoir	Level in reservoir (2)
Maximum barrier pressure	150 psig (10.3 barg)	Limited by Plan 53B system components	Limited by Plan 53C system components	Limited by barrier fluid source	Limited by Plan 54 system components	Limited by Plan 54 system components
Minimum barrier pressure (3)	Limited by component selection	Limited by component selection	100 psig (7 barg)	Limited by component selection	Limited by component selection	Limited by component selection
Circulation provided by	Circulation device on seal	Circulation device on seal	Circulation device on seal	Differential pressure in supply and return lines	Pump in Plan 54 system	Pump in Plan 54 system
Cooling provided by	Internal cooling in reservoir	External seal cooler	External seal cooler	N/A	Internal cooler in reservoir or external cooler	External cooler
Suitable for remote locations (4)	No	Yes	Yes	No	Yes	Yes (with limitations)
Affected by ambient temperature	Yes - minimal	Yes	No	No	No	No
Ability to track seal chamber pressure	No	No	Yes	No	No	No
System components exposed to process	No	No	Yes	No	No	No
Suitable for dirty applications	Yes	Yes	No	Yes	Yes	Yes
Barrier fluid limitation - selection	No	Limited by bladder compatibility	Limited by piston accumulator compatibility	No	Oil based barrier fluids preferred	Oil based barrier fluids preferred
Maintenance location	At each pump location	At each pump location	At each pump location	At each pump location	At each pump location	At central location
Refill considerations	Refill under pressure	Refill under pressure	Refill under pressure	N/A	Refill into atmospheric reservoir (open system)	Refill into atmospheric reservoir (open system)

Notes

- (1) Pressure is constant ratio relative to the reference pressure or seal chamber pressure.
- (2) Level in reservoir measures the aggregate leakage of all seals supported by the system. Monitoring individual seal leakage requires manual procedure.
- (3) All systems are subject to variations in barrier fluid pressure as a function system design, component selection and/or utility pressures. This must consider the minimum differential pressure relative to the seal chamber.
- (4) With air-cooled or process fluid cooled seal cooler



## APPLICATION CONSIDERATIONS

When the application conditions for a mechanical seal are reviewed, the reviewer commonly considers the process fluid, process pressures, process temperatures, and the equipment operating speed. While these parameters are suitable for a generic review of the application, a more detailed review is required for properly selecting the most appropriate piping plan and component selection.

### *Defining seal chamber pressure*

All dual pressurized seal applications share one common requirement – the pressure in the barrier fluid system must be maintained at a pressure greater than the seal chamber pressure. Conceptually, that is a simple requirement. There are only two parameters: the seal chamber pressure and the pressure differential. This however becomes more complex when we start to examine our knowledge of the actual seal chamber pressure and the requirements for the differential. Some of these considerations are a function of the piping plans and its components but some are a function of other factors such as the pump design, process stability, and operating procedures.

#### *1. Pump design*

The seal chamber is the cavity that is located at the interface of the rotating shaft and the outside of the fluid-containing, pressure casing of the centrifugal pump. It is easy to think of the pressure in the seal cavity as being at the same pressure as inside the pump. This becomes less clear when we recognize that there is not just one pressure in the pump. The suction nozzle is naturally at suction pressure and the discharge nozzle is at discharge pressure. The seal chamber pressure is normally somewhere between these extremes. The actual pressure will depend upon the construction of the pump. There have been many commonly applied “rules of thumb” to estimate the seal chamber pressure as a function of the pump design and the suction and discharge pressure. These normally take the form of the following equation.

$$P_{sc} = P_s + K(P_d - P_s)$$

where     $P_{sc}$  = seal pressure  
            $P_s$  = suction pressure  
            $P_d$  = discharge pressure  
            $K$  = design factor based on pump design

The value of  $K$  can vary from 0 to 1.0 depending upon the pump design.

While the values calculated by this method are useful, they must be considered as only an estimate. The actual value may be affected by the condition of the pump and clearances in critical bushings or wear rings. It can also be modified by a number of other design or operational factors described below. The pump OEM can provide the most accurate estimate for their specific pump design and some OEMs routinely put this information in the pump data sheet. The most accurate method for determining the pressure in the seal chamber is to install a pressure indicator or pressure transmitter directly into the seal chamber. Many pump designs already have a port into this area or seal OEMs may be able to design a port into the seal gland for this purpose.

#### *2. Special design features*

Although the estimation method described above is reasonably accurate, it does not take into account some design features or variables on the pump. These include the use of an inducer, the impeller setting for some pumps, and the use a bushing in the seal chamber.

An inducer is a device used to increase the NPSH entering the pump impeller. This may be required for applications with a low NPSH<sub>A</sub>. It is also very common on some high speed pump designs. The inducer itself is an axial flow impeller which essentially supercharges or increases the pressure entering the impeller. This also increases the effective suction pressure of the impeller and can increase the seal chamber pressure. The pump OEM can provide details on the expected increase in pressure.

Certain pump designs are provided with features on the back of the impeller designed to modify the seal chamber pressure. These pumping features are referred to as back vanes or pump-out vanes. In normal operation, these vanes expel fluid radially outward from behind the impeller reducing the pressure at the seal chamber. Their effectiveness in lowering the pressure is a function of the clearance between the impeller and the back plate on the pump. As the clearance becomes smaller, the back vanes become more effective and can actually lower the pressure in the seal chamber below the suction pressure in the pump. It is difficult to estimate the effect of this feature since the impeller clearance is set in the field and subject to significant variations.





Seal chambers are commonly provided with a bushing in the back of the seal chamber. This is often a historical remnant of stuffing box designs and was used to prevent packing extrusion. In most cases, these features have a significant clearance and do not modify the seal chamber pressure. There are applications however where it may be desirable to increase the seal chamber pressure. An example would be to increase the pressure to prevent flashing or vaporization of a light hydrocarbon with a high vapor pressure. In these cases, the seal OEM may specify a close clearance throat bushing which, in conjunction with a Plan 11, will locally increase the seal chamber pressure. While this practice is not commonly used with a dual pressurized seal, it may be used in special circumstances. The seal OEM can provide additional information on the effect of this feature.

### *3. Variable speed drives*

Variable speed drivers on centrifugal pumps offer a potential to adjust the pump operating speed to meet the demands of the application. In many cases, this allows the end user to operate their equipment more efficiently and provide better control of their process conditions. This has become a more common practice as variable speed controls have evolved and end users have gained more experience with this option. While variable speed operation does not directly affect the seal chamber pressure, it does affect the differential pressure across the pump. On many pump designs, changes in the discharge pressure will have some impact on the seal chamber pressure. When variable speed drives are used, both the minimum and maximum operating speeds of the equipment must be considered in estimating the seal chamber pressure.

### *4. Process stability*

The most often used reference for obtaining data for the pump suction and discharge pressures is the pump data sheet. It is often said that the pump data sheet contains the one set of operating conditions at which the pump is guaranteed never to operate. The accuracy of the data sheet becomes more questionable if the data sheet is old (outdated) or conditions in the process have changed over time. The most accurate method for determining the pressures in the pump is to obtain real time from the plant DCS or from local indicators at the equipment. Many pumps lack local suction pressure measurements and these may have to be obtained from an upstream source and corrected for line losses in the suction piping.

Even taking real time data has limitations. This represents only a snapshot of the pressures at that moment and may not capture the full range of pressures that occur during operation. Most pump data sheets have pressure data for minimum suction, rated suction, and maximum suction. It is critical that the full range of suction and discharge pressures is considered. It is also critical to recognize these may include both static and dynamic conditions in the pump.

### *5. Batch processes*

Batch processes by their very nature imply a set of varying operating conditions based on cycling through a process. Pressures, flow rates, temperatures, and process fluid properties may change through each cycle. There may also be additional conditions related to filling the batch, emptying the batch, and cleaning the equipment between batches. The conditions in the pump and seal chamber must be evaluated for all of these phases and the extremes considered in the system evaluation.

### *6. Upsets and outages*

Steady state conditions represent the most common operating conditions for most equipment. Upsets in the system can however expose the equipment to a significantly different set of conditions. This may be a minor variation resulting from changes in the process fluid or a major variation resulting from the loss of an upstream or downstream piece of equipment, loss of a required utility, or failure of the pump itself. While it may be impossible to predict every potential upset scenario, a robust process and equipment FMEA can provide useful insights and help establish design requirements and redundancies.

### *7. Special process considerations (design for discharge pressure)*

Many centrifugal pumping systems are designed with a check valve downstream from the pump discharge. This prevents downstream pressures from flowing back through the pump when it is shut down or goes into standby conditions. The upstream suction valve is open to prevent pressurization of the pump. In this scenario, seal chamber will be exposed to pressures ranging from the suction pressure at standby up to the pressures developed under normal operating conditions. This scenario can change if the suction valve on the pump is closed while the system is under pressure. Small amounts of leakage past the discharge check valve can quickly increase the pressure in the pump and the seal chamber up to the discharge pressure.

Some end users consider this scenario as a design requirement on highly hazardous services. They require that the minimum barrier fluid pressure be determined by considering the full discharge pressure in the seal chamber. While this is possible, it can lead to



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significant challenges and compromises in both the mechanical seal and system design. Other solutions such as suction valve operating procedures, locking the suction valve open, or a pressure relief valve across the suction valve are used to prevent high pressures in the pump during standby conditions.

#### *8. Nature and characteristic of the process fluid*

The nature of the process fluid can have a large impact on the selection of the Plan 53 system. If the fluid is capable of being pumped by a centrifugal pump it is assumed that it has a reasonably low viscosity. Most pump applications are also assumed to be free from large particles or solids. In reality, centrifugal pumps can be used to pump a wide range of viscosities as well as pump fluids from ultrapure liquids to high concentration slurries. One of the common reasons why Arrangement 3 seals are selected is because the process fluid is unsuitable for reliable seal operation. The properties of the process fluid need to be fully understood when selecting the appropriate piping plans.

The piping plan most impacted by the process fluid is the Plan 53C. The sliding nature of the piston in the accumulator requires that the walls of the cylinder in the accumulator are free from a build-up of debris, plating or pitting. The process fluid must not solidify, crystallize, or precipitate dissolved solids in the accumulator. Solids or debris in the process must also not plug or block the reference line between the seal chamber and the accumulator. This may be a challenge for processes with high freezing points since the reference line and the accumulator will be at ambient temperature. Other piping plans do not directly expose the system components to the process so there is less of an impact from the process fluid.

The process fluid can have an underappreciated impact on the seal design. Fluids containing dirt, debris, or solids may require additional evaluations when selecting the inner seal orientation and the need for additional piping plans to support the inner seal. It is common to design seals in dirty applications with the process fluid on the outside (or OD) of the seal. This allows the rotation of the seal components to centrifugally expel higher density solids away from the seal. This can help minimize damage to the seal components or prevent the build-up of solids from causing gasket seal hang-up. In an Arrangement 3 seal, this orientation would commonly be described as a face-to-back orientation (FB). This orientation will have the high pressure barrier fluid on the inside (ID) of the inner seal and the process fluid on the OD. This normally reduces the pressure rating of the seal. Additional details on this topic are discussed in Seal Design Considerations below.

If other orientations such as face-to-face (FF) or back-to-back (BB) are required due to the differential pressure across the inner seal, it may be necessary to protect the inner seal by adding an additional piping plan. A Plan 12 with a filter or a Plan 31 with a cyclone separator may provide some protection by preventing larger solid particles from entering the seal chamber. A Plan 32 external flush can provide the best operating environment for the inner but with additional complexity, cost, and product dilution considerations. The actual seal installation envelope and seal design need to be evaluated to determine if an additional inner seal piping plan can be added due to space constraints.

#### *9. Considerations for high temperature applications*

High temperature conditions present a number of challenges in the design of the mechanical seal and system. Relative to the piping plan, these challenges include the ability to handle the additional heat load from the process and the ability to circulate barrier fluid throughout the seal and system. High temperature applications have a natural tendency to transfer heat from the hot process conditions in the casing to the cooler barrier fluid. This is referred to as “heat soak” and is often the greatest source of the heat load into the barrier fluid system. There are commonly used methods of estimating heat soak provided in API 682 and other published sources. The combination of the seal generated heat and heat soak can be significantly greater than heat loads found in typical seal applications. For this reason, the seal cooler or heat exchanger must be appropriately sized to control the barrier fluid temperature to an acceptable level.

Even with sufficient heat removal, the barrier fluid can be exposed to extreme temperatures as it circulates through the mechanical seal. This can lead to thermal breakdown of the barrier fluid and, over time, degrade the properties of the barrier fluid. To help prolong the operating interval for the equipment and reduce maintenance requirements, many end users specify large capacities in the circulated volume of barrier fluid. For example, Plan 53A systems are often provided with 75 liter (20 gallon) reservoirs in high temperature services. The larger size reservoirs also allow larger internal cooling coils to be installed to assist in heat removal. Plan 54 systems also naturally have large reservoirs which is beneficial in high temperature applications. Plan 53B and 53C systems typically have small circulated volumes and will require special considerations.

Plan 54 systems have another significant benefit over Plan 53 systems – Plan 54 systems provide a forced circulation of barrier fluid at



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all times. This can be a significant advantage especially during standby conditions while the pump is at temperature. Plan 53 systems are designed to thermosyphon during standby which can help control barrier fluid temperatures. The forced circulation of the barrier fluid in a Plan 54 however is far more effective and can provide constant circulation regardless of whether the pump is in operation or in standby. The forced circulation also allows seal designers to create very effective flow paths within the mechanical seal to ensure an even distribution of the barrier fluid in all parts of the seal. These features are often too restrictive to be used with the pumping ring driven circulation of Plan 53s. The highly effective cooling found in Plan 54's can pose problems for some applications. Many high temperature applications require the process fluid to remain above a specific temperature to prevent solidification, crystallization, or excessively high viscosity. During standby conditions, the process fluid in the seal chamber can be reduced to the point where the fluid properties adversely affect seal or pump performance.

#### *10. Considerations for low temperature applications*

Low temperature applications are commonly found in processing light end hydrocarbons and some chemical processes. Low temperature services may require seal designs with special elastomeric gaskets (e.g. low temperature nitrile or fluorosilicone) or designs which eliminate all elastomeric gaskets. Barrier fluids present one of the biggest challenges for these applications. In some services, the barrier fluid will be in contact with seal components which are at operating temperature. This requires that the barrier fluid maintains a sufficiently low viscosity at low temperatures. This may require special barrier fluids such as glycol/water mixtures or alcohols instead of more commonly used oil-based barrier fluids. The selection of the barrier fluid can also impact the selection of the piping plan. Some barrier fluids are difficult to pump with a PD pump and may limit the use of Plan 54 systems. Special pump designs with special warming chambers may effectively isolate the seal chamber from the cold temperatures and mitigate most the challenges in these applications.

### **PIPING PLAN PRESSURE VARIATIONS**

It is common to think of the barrier fluid pressures as being constant in most piping plans. One of the primary functions of these piping plans is, after all, to create and control the pressure. This is often not the case and, in some piping plans, the variations present significant challenges for the operation of the seal. The manner in which the pressure is generated and regulated is one of the primary variables. In addition, variations in plant utilities and ambient conditions can drive variations in the barrier fluid pressure. It is critical to understand the magnitude of the variations when selecting the mechanical seal and designing the barrier fluid system.

#### *Plan 53A*

A Plan 53 is pressurized from an external source of nitrogen. Most plant nitrogen systems are very reliable and have suitable pressurized volumes to minimize pressure fluctuations. The Plan 53A however does not operate directly on nitrogen pressure in the supply header. A forward pressure regulator is provided between the supply header and the reservoir to regulate the Plan 53A system to the correct pressure for the application. It is a relatively simple procedure to adjust the regulator until the desired pressure is achieved.

Pressure regulators are commonly available in either a pressure relieving (self-relieving) or non-relieving design. A relieving pressure regulator will maintain the downstream pressure at a specified pressure even if the downstream system attempts to create a higher pressure. It will achieve this by bleeding the high pressure through the regulator until it reaches the set pressure. A non-relieving regulator will pressurize the downstream piping to the set point but not bleed off the downstream pressure if it is increased above the set level. It would appear that a self-relieving regulator would be the first choice for a Plan 53A but this is not the case. If there is a system upset and high pressure process fluid enters the barrier fluid, a relieving pressure regulator could bleed a combination of nitrogen, barrier fluid, and process fluid directly to the atmosphere. For this reason, most Plan 53A system will use a non-relieving pressure regulator. This is also the recommendation in API-682.

The use of a non-relieving regulator does have some negative implications. The pressure in the reservoir can become higher than the intended set pressure. This can occur for several reasons. When the system is originally set to the correct pressure, there is a volume of gas above the barrier fluid in the reservoir. As ambient temperatures increase, the temperature in this captured gas volume will increase resulting in higher pressures. Pressures can also increase when an operator adds make-up barrier fluid into the reservoir. The added fluid will compress the volume of captured gas over the barrier fluid resulting in an increase in pressure. Finally, the barrier fluid volume will increase due to thermal expansion (or a decrease in density) as it goes from a lower temperature at standby to a higher temperature under operation. All of these factors can result in pressure fluctuations in a Plan 53A. In practice, these variations are seldom a major concern but they should be considered when performing a system review.



#### *Plan 53B*

A Plan 53B replaces the reservoir with a bladder accumulator. The interaction of the pressurized gas in the bladder with the barrier fluid in the accumulator creates the system pressure without the negative impact of gas absorption into the barrier fluid. As barrier fluid is added into the Plan 53B system, the bladder is compressed with a corresponding increase in pressure. As barrier fluid is consumed due to normal seal leakage, the bladder expands resulting in a decrease in pressure. This fluctuation in pressure is a normal condition for all Plan 53B systems and defines the strategies used to monitor seal performance.

Most end users and industry standards define a minimum time between operator interventions to add barrier fluid to the system. This generally ranges from 25 to 28 days. This serves as the basis for the system design calculations which define the size of the accumulator, the pre-charge pressure, and the pressure variations in the system. Unfortunately, the pressure of the gas in the bladder accumulator is also impacted by the ambient temperature. As the ambient temperature increases, the temperature of the gas in the bladder rises causing an increase in the barrier fluid pressure. This can be further impacted by solar heating of the accumulator if it is exposed to direct sunlight.

Plan 53B systems were used for many years without a thorough understanding of these variables. This resulted in more frequent refill rates or false indications of a seal failure. One of the first published methods for examining Plan 53B performance can be found in API 682 Annex F. This analysis considers the relationship between these variables throughout the range of minimum to maximum ambient temperatures including the impact of solar heating. It also describes different alarm strategies (fixed or floating) that can be used to indicate refill and shutdown alarms. While this is an informative annex in the standard, many end users are starting to use it to better understand their system performance.

The outcome of this analysis can be enlightening. Depending upon the range of operating temperatures, seal chamber pressure, and system design, a Plan 53B can be exposed to a very wide range of operating pressures. The high operating pressures of the Plan 53B even for moderate seal chamber pressures can significantly impact the seal selection, seal orientation, and even seal face materials. Mitigation techniques such as sun shields, heat tracing the accumulator, and auto-refill systems are also options which may be considered to reduce these pressure variations. While Plan 53Bs offer some unique benefits and continue to be a popular selection for new seal systems, they should be applied only after a thorough system analysis.

#### *Plan 53C*

A Plan 53C system is a unique option in that the pressurization source for the system is the pump process itself. This has the dual benefit of being a self-energizing system as well as being a pressure tracking system. While the pump is being initially pressurized, the barrier fluid is also pressurized. As the seal is exposed to normal system variation or upsets, the barrier pressure automatically adjusts to maintain an acceptable pressure differential across the inner seal.

One of the differences between the Plan 53C and other options is that the end user does not have the ability to adjust the barrier fluid to a specific pressure. There is a limited ability to define the pressure of the barrier fluid by selecting the ratio of the piston accumulator. This however is a one-time selection that is made during the initial purchase of the accumulator and cannot be altered by the end user after installation. Under low pressure seal chamber conditions, this may result in relatively low differential pressure across the inner seal. To maintain the pressure differential during operation, the piston must slide in the bore of the accumulator. To overcome gravity and friction losses in the piston, Plan 53 C systems normally have a minimum pressure requirement. Operation of the system at lower pressures can result in erratic performance and loss of pressurization of the barrier fluid.

The Plan 53C's pressure variation will be directly related to the variations in seal chamber pressure. For a piston accumulator with a 1:1.1 ratio, a pressure of 7 bar (100 psi) in the seal chamber will result in a barrier pressure of 7.7 bar (110 psi). If the seal chamber pressure increases to 14 bar (200 psi), the barrier pressure will automatically increase to 15.4 bar (220 psi).

In principle, the Plan 53C offers some of the best features of any dual pressurized piping plans. If the process fluid is not ideal however, the hang-up of the piston and damage to the dynamic gaskets in the accumulator can result in erratic system performance.

#### *Plan 54*

Since there is no defined Plan 54 system, there is no generalized estimate of the variations in seal system performance. The complexity of the seal system and the selection of system components will dictate the system performance. A properly designed system though can exhibit the most stable barrier fluid pressure of any of the options. Plan 54s also have the most predictable flow rates of barrier fluid through the system remaining relatively constant during both standby and operation of the pump.





## SEAL DESIGN CONSIDERATIONS

Mechanical seals are designed to operate over a range of application conditions. While end users and seal OEMs always consider the application conditions of the pump, it is less common to consider the full range of application conditions for the piping plan. The piping plan conditions will have an equal impact on the performance and will introduce additional design requirements for the seal.

Most mechanical seals are designed to operate with a high pressure on the outside diameter (OD) of the seal faces. In this OD pressurized orientation stresses in the seal faces are primarily in compression. This is beneficial since typical seal face materials have higher allowable working stresses in compression than in tension. Most seal faces designs also control face flatness by balancing thermal distortions against pressure distortions and using OD pressurization on the seal works well with this design practice. Conversely, seals may need to be designed with the inside diameter (ID) exposed to the higher pressure. This places the seals face into tension and can severely limit the allowable differential pressure across the seal. It is possible to increase the ID pressure rating for the mechanical seal by using two hard faces on the inner seal although this may limit the selection of barrier fluids in some applications. With most seal product lines, seals designed for OD pressurization will have higher pressure ratings that comparable seals designed for ID pressurization.

When two mechanical seals are packaged into an Arrangement 3 seal assembly, there are three general orientations that are common: face-to-back (FB), back-to-back (BB), and face-to-face (FF). All of these orientations are used in industry. Each orientation has strengths and weakness which may make it more suitable for a specific application. The allowable differential pressure rating and the direction of pressurization are two characteristics which must be compatible with the barrier fluid pressure variation of the proposed piping plan.

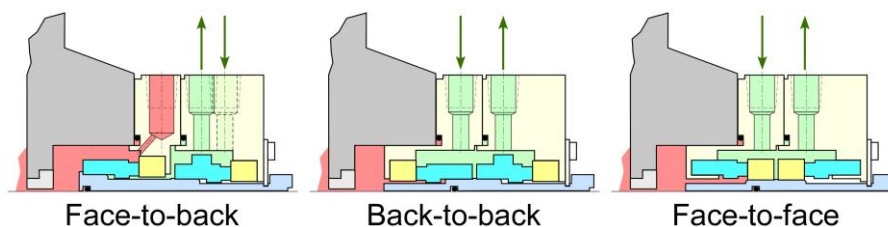


Figure 8 Seal Orientations

When considering the differential pressures on the seals, it is important to consider three separate cases. All dual pressurized seals should have the barrier fluid pressurized prior to filling the pump with process fluid (although on a Plan 53C, this will occur automatically as the pump is pressurized). This will prepare the pump for operation and prevent process fluid from migrating across the inner seal faces into the barrier fluid. This condition (considering all of the variations in the piping plan) represents the maximum differential pressure across the inner seal in one direction. After the pump is pressurized, the differential pressure across the inner seal will be less as the seal chamber reaches its normal operating pressure. This condition represents differential pressure under normal conditions. Finally, a failure of the outer seal or a malfunction in the piping plan can result in a complete loss of barrier fluid pressure. The inner seal will now be pressurized in the opposite direction and may need to operate for a short period of time in this condition while the pump is shut down.

There is no one orientation which is superior for all operating cases. The Plan 53B however has the largest potential range of barrier fluid pressures which makes it less suitable for dual seals in an FB orientation. Plan 53C systems can provide the lowest differential pressures across a wide range of seal chamber pressures. Plan 53A and Plan 54 systems can provide very stable operating pressures and may be suitable for most applications.

## UTILITY CONSIDERATIONS

Many of the dual seal piping plans have accessories which rely on outside utilities for proper operation. In a plant environment, these utilities are often readily available and may already be used on the pump for other purposes. In other cases, especially remote locations, the choice of external utilities can be very limited. This may not only impact the selection of the accessories used in a piping plan but may impact the selection of the piping plan itself.





### *1. Nitrogen*

Nitrogen is commonly used throughout most plants for a variety of purposes. Nitrogen headers are found through all parts of the most plants and are readily accessible for use in a sealing system. Remote locations in a plant, such as a tank farm, may not have nitrogen available or local nitrogen needs may be met with nitrogen bottles or “six packs”. Other remote locations such as unmanned pipeline stations may have even more limited resources since they are not only remote but are also only periodically visited by maintenance personnel. Locations without nitrogen should avoid the use of a Plan 53A and consider other options.

### *2. Cooling water*

Cooling water is the most effective and efficient cooling medium for all of the mechanical seal piping plans. The high overall heat transfer coefficient, high specific gravity, and high heat capacity make it an ideal cooling medium. This allows for smaller seal coolers (or heat exchangers) and more compact system designs. It also allows for a more stable barrier fluid temperature since most cooling water systems are maintained within a relatively narrow range of operating temperatures.

Not all locations have access to cooling water. Like nitrogen, remote locations often do not have a reliable source of cooling water. In some plants, the cooling water system may already be heavily utilized and the requirement to add an additional load on the system may be met with resistance. The quality of the cooling water may also be poor and the impact on long term system performance should be considered.

Air-cooled seal coolers are an option for these applications. These units range from small sections of finned tubing relying on natural convection to very large banks of “radiators” with fans providing a forced draft to increase convection. The design and capacity of the air-cooler is entirely dependent on the heat removal requirements, the allowable system temperature, and the ambient temperature. The variations in the ambient temperature can be quite large in many locations resulting in large swings in barrier fluid temperatures. For the Plan 53 systems in standby conditions, the barrier temperature in the cooler can be equal to the outside ambient temperature. The system designer needs to consider the resulting barrier fluid viscosity under the coldest ambient temperatures to ensure the seal’s pumping device can initiate circulation when the pump is started.

### *3. Electricity*

Electricity is available at almost every pump installation. This is due primarily to the fact that most pumps are driven by electric motors. On high energy pumps, this source of electricity may not be at a suitable voltage for the sealing system accessories. Fortunately, many other components in the pump, instrumentation, and control systems also use electricity so finding a suitable source is seldom a problem.

The most commonly used seal system accessory that uses electricity is a forced convection air-cooler. Most Plan 54 systems also use an electrically driven pump for the pressurization and circulation of the barrier fluid system. Some end users specify redundant accessories which do not rely on electricity such as an air-driven pump in a Plan 54 to allow for short term operation in the event of a local disruption of electricity at the pump. This would allow for the system to remain pressurized and the seals to function normally until the power is restored.

## **BARRIER FLUID CONSIDERATIONS**

The barrier fluid is perhaps the most critical element in any dual pressurized seal application. It is the fluid on which both the inner and outer seal will operate during normal operation. There will be a small amount of barrier fluid which leaks into the process fluid and the impact of this must be considered relative to process compatibility and pump performance. There are reference materials available which discuss the requirements for barrier fluid in more detail.

The selection of the piping plan and the system accessories will also be impacted by the selection of the barrier fluid. Most barrier fluids can be categorized as either a water-based fluid or hydrocarbon-based fluid. Water-based fluids include water, water glycols, and alcohols. Hydrocarbon-based fluids include diesel, mineral oils, and synthetic oils. Water-based systems may require special material considerations due to corrosion or chemical compatibility. They may also require special considerations due to freezing in colder climates. Oil-based systems may require special consideration for handling the high viscosities during colder temperatures.

Plan 54 systems have an additional consideration with barrier fluid selection. The pressurization/circulation pumps in most Plan 54 designs are positive displacement (PD) pumps. While there are many different types of PD pumps used in these systems, most rely on



contacting or sliding elements in the PD pump itself (e.g. gears or vanes) to create the pumping action. These types of pump are normally designed for use with moderate viscosity oils with good lubricating properties. Using these pumps with a water based fluid is generally not recommended or will result in lower system reliability.

Plan 53 systems rely on the pumping action of the rotating seal components to circulate the barrier fluid through the system. This requires that the barrier fluid is at a reasonable viscosity during all operation conditions to enable proper circulation through the system. It also requires that the piping in the Plan 53 is optimized to reduce the friction losses in the system. This includes using large diameter tubing, designing short tubing runs, using smooth tubing bends, and minimizing or eliminating fitting or valves in the flow path. Plan 54 systems generally use a forced circulation from a PD pump. This allows for the design of more complex piping plans, permits the use of accessories in the circulation line (e.g. filters), and minimizes the concerns about the actual system resistance curve. This not only includes the external elements of the piping plan but also the flow path of the barrier fluid in the mechanical seal itself.

## AMBIENT TEMPERATURE CONSIDERATIONS

Many of the concerns with ambient temperatures have been covered in other sections. The range of temperatures from the coldest temperatures in winter to the hottest temperatures in summer can impact many aspects of the system design and operation. These can be considered to affect several general areas.

### 1. Barrier system pressure

The barrier fluid pressure is controlled by accessories in the piping plan. The Plan 53B uses a bladder accumulator with a pressurized gas acting as the mechanism to pressurize the barrier fluid. Changes in ambient temperature will have a direct impact on the gas pressure and thereby the entire system pressure. While this effect is well understood and straightforward to calculate, its overall impact on the system can be significant and is often underestimated. Plan 53A systems provided with the standard non-relieving pressure regulators will also experience some changes in pressure but with less of an overall impact on the system performance.

### 2. Barrier fluid properties

The barrier fluid temperature is established at the equilibrium condition between the heat input into the fluid by the seal generated heat (and pump soak) and the heat output into a seal cooler or heat exchanger. Most seal users consider the equilibrium temperature during normal operating conditions. Under standby conditions, these same factors continue to be in affect normally resulting in lower heat input relative to the cooling capacity. In low ambient temperature conditions, air-coolers have the ability to significantly decrease the barrier fluid temperature which can result in excessive viscosity or solidification of the barrier fluid.

### 3. Variations in ambient temperatures

The ability of an air cooler to dissipate heat into the atmosphere is a direct function of the differential temperature between the barrier fluid and the ambient temperature. In some regions, the difference between the maximum summer and minimum winter temperatures may be extreme with a world record near 100°C (180°F)! Although most plants will not experience this range of temperatures, the actual range at many operating plants can be unexpectedly high. These ranges will result in very different operating temperatures for the barrier fluid system. These extreme must be considered during a system evaluation for both normal operation and during standby conditions.

### 4. Plant utilities

Cooling water is commonly used in seal coolers or reservoirs in all of the dual seal piping plans. During standby conditions, some users shut off the cooling water especially if the equipment is not expected to operate for an extended time or if the equipment is undergoing maintenance. If water is left in (or blocked in) the piping, tubing, or system accessories and the ambient temperature dips below freezing, the resulting ice formation can damage system components. When an unusual cold front moves through certain regions, the resulting orders for new seal coolers indicates that this condition may be more common than many end users consider.

## PUMP AND DRIVER CONSIDERATIONS

### *Available space and installation envelope*

Most seal user use the phrase that the mechanical seal is installed in the seal chamber of the centrifugal pump. This is partially true. The mechanical seal is also installed outside of the seal chamber in the space between the seal chamber and the bearing bracket. Piping going to and from the seal also extends from the seal gland, through the bearing brackets, to connect with external process fluid, barrier fluids, and utility locations. The mechanical seal is not simply a single component but is a system which is integrated into



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the pump and pumping system. With this perspective, it is easy to see how the design of the pump and the available physical space can influence the design of the seal and the selection of the piping plan.

Plan 53 systems rely on the pumping action of the rotating components within the mechanical seal. There are however a number of important design factors that allow a dual seal to effectively circulate barrier fluid. The design of the pumping ring, the axial location and size of the ports relative to the pumping device and the angular orientation of the inlet and outlet ports (as viewed from the end view) are critical design decisions. All of these factors are impacted directly by the seal design. Seals which must be installed deep into the seal chamber have limited options for porting designs. Pumps with a large distance between the seal chamber and the first obstruction have more flexibility in the porting design and can provide more effective fluid circulation. Seals with 360° bearing brackets have limited windows for porting to connect to the gland while pumps designs with wide open brackets can allow for more flexibility in seal design. Generally the more constricted the installation envelope, the more difficult it becomes to provide an optimal pumping ring driven system. In these cases, the use of a Plan 54 system may be a better selection.

#### *Power requirements*

All mechanical seals consume power. This power is required to overcome frictional forces between the faces and is a function of the differential pressure across the seal faces. The higher the pressure in the barrier fluid system, the larger the power requirement for the seals. Other mechanisms such as fluid shear in the seal chamber and the pumping action of the barrier fluid create additional loads from the seal. This load is carried by the pump shaft and adds directly to the power requirements on the pump driver. In most pump applications, the mechanical seal power requirements are only a small fraction of the hydraulic power requirements and it is frequently ignored. This is however not always true and can create problems in some lower duty applications.

Low flow rate, low differential head applications require small horsepower drivers. Even if these applications have a high suction pressure, the power requirement for the pump is low. Dual mechanical seals will have a higher power requirement than a single seal. As the pressure in the barrier system increases, the power requirement will also increase. Some piping plans such as a Plan 53B may require a very high differential pressure across both the inner and outer seals due to the inherent variation in the system pressure. This can result in high power requirements for the mechanical seal relative to the hydraulic power and this condition can overload the pump driver. This can also be seen as a high start-up torque on the seal which prevents starting the pump. The seal power and torque requirements (both start-up and operational) should be communicated to the purchaser to allow the correct size driver to be selected. Piping plans with lower and more stable system pressures can reduce these loads to a minimum.

### **PUMP AND PIPING PRESSURE CASING CONSIDERATIONS**

All pumps and their connected process systems are designed for specific pressure requirements. This is normally specified as the maximum allowable working pressure (MAWP) of the system. There is a requirement that all components in this system are rated at a minimum of the MAWP of the process system. API 682 defines the combination of the mechanical seal and its associated pressurized components as the pressure casing. The pressure casing is the “composite of all stationary pressure-containing parts of the seal, including the seal chamber, barrier or buffer fluid chamber, containment seal chamber, and seal gland plate...” It further increases the scope to include piping and accessories connected directly to the gland plate. All pressure casing components of the mechanical seal and system must be rated for the MAWP of the pump casing. Even if application conditions (e.g. suction and discharge pressure) are very low, the pressure casing components must be rated for the MAWP of the pump casing. The philosophy behind this requirement is that a component cannot be attached to an existing pressurized system if it will lower or compromise the rating of the overall system.

This may have an implication on the selection and design of the piping plan for dual mechanical seals. Fortunately, seal OEMs have many years of experience in designing systems to these requirements and all of the discussed piping plans have designs that can be specified across a wide range of pressures. On pumps with a high MAWP pressure rating, this may significantly increase the cost of the piping plan. Some end users will examine their process designs for additional protections (e.g. pressure relief valves or PRV) that can prevent excess system pressure and allow a deviation from this requirement.

This reverse of this consideration also needs to be applied when the designers examine the Plan 53 or Plan 54 system designs. The mechanical seal piping plan should not be designed so that it can create a higher pressure in the barrier fluid than the MAWP of the pump casing. In most cases, the scope of this consideration should extend to the process piping and pumping system components. This consideration applies not only to normal barrier fluid pressures but also to variations in the piping plan pressure. These variations include the inherent variations in the different piping plans described above. It can also apply to pressure upsets such as a clogged filter or blocked return line in a Plan 54 system. There are number of strategies such as the use of PRVs to help provide additional



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protection for the system.

## **MAINTENANCE CONSIDERATIONS**

All mechanical seals will consume barrier fluid through normal leakage from the seal faces. While the leakage rates are typically very small, they will vary depending upon factors such as the differential pressure across the seal, the size of the seal, the operating speed, and even the sealed fluid. In most dual seal systems, the loss of fluid comes from a barrier fluid system with a finite volume and this lost fluid must be replenished to bring the system back up to the normal working volume. The required working volumes will be a function of the normal leakage rate and the difference in system volumes at the fill and maintenance alarm level. This is a relatively direct measurement for Plan 53A and Plan 53C systems. Plan 53B systems are monitored on system pressure with numerous factors other than leakage impacting the system pressure. API 682 gives a general target of 28 days of continuous operation before there is a need to add barrier fluid to the system.

The procedure for adding barrier fluid depends upon the piping plan and system design. All Plan 53 systems are closed systems with the entire barrier fluid volume maintained under pressure. This requires that adding barrier fluid is performed on a pressurized system. Many systems will have connection ports with a high pressure fitting that allow for easy connection from an external fill cart. Other systems will have small reservoir and hand pump integrated into the system to allow for easy fluid addition under pressure. Other systems may even be permanently connected to an external source of barrier fluid and refilling only requires opening the valve in the fill line. The actual procedure will depend upon the piping plan and system design and will be accompanied an indication that the system has reached the maximum working volume of barrier fluid. Operators should ensure that their procedures are properly followed and that they do not overfill the systems. Regardless of the actual process, these methods are manual in nature and require operator intervention.

Almost every system comes with options to provide automatic refilling of the piping plan when a low level maintenance alarm is reached. This option has the benefit of being automatic and minimizing the need for operator intervention. The drawback is that introduces additional complexity into the system design and the reliability of the seal may now be tied to additional external utilities. Operators also use maintenance intervals a crude indicator of seal performance. Some operators may lose visibility of the refill rate in an automatic system. Even with these considerations, automatic refill systems have can be found in many reliable dual seal installations.

Plan 54 systems can range from simple to very complex and the required maintenance will depend largely on the system design and types of accessories included in the system. It is common to find filters on many Plan 54s. For a small system, this may include a screw on hydraulic filter resembling an automotive oil filter that is changed at regular intervals. Larger systems frequently have dual filters with a by-pass capability to allow for changing out a removable filter element while the system is in operation. These filters normally use differential pressure to indicate the need for maintenance for the system. Larger units will also have redundant heat exchangers to control temperatures in the Plan 54. The thermal performance of these systems is normally used to indicate the need to clean the heat exchangers or purge the cooling water side of the heat exchanger. While larger Plan 54 systems may seem to have a more complex system and require additional maintenance, the single point nature of these maintenance activities can prove to be more efficient than maintaining multiple autonomous systems.

## **INSTRUMENTATION CONSIDERATIONS**

One of the significant revisions in API 682 Fourth Edition was changing from a default of using switches and local indicators to using transmitters with local indication. For many years, there was a perception that transmitters were a more costly option for instrumenting sealing systems. There could indeed be significant costs associated with retrofitting a switch to a transmitter in an operating unit. These costs however where largely tied to running additional wires, integrating the signal into the plant DCS, updating the wiring documentation for the plant, and writing new operating procedures. These costs were much higher than the cost of the hardware itself. For new systems though, the incremental costs are extremely small. The benefits using for transmitter however can be significant.

A switch is an indication that a pre-set level for a given parameter has been reached. This could apply to fluid levels, temperatures, flow rates, and pressures. When a switch activates an alarm, the values of the specific parameter before or after the alarm was activated are not known. For example, an alarm from a high level switch in a seal reservoir could represent a rising level which reached the alarm level after many months of operation. It can equally represent a sudden rise in level over only a few minutes. Even though these two scenarios deserve different responses, the operator does not know which to perform from the alarm alone.



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Transmitters can allow the operator to see real time data for the measured parameters. This allows them to trend data over time and better understand the real performance of the system. Trending data allows the operator to know how to react to changes in the parameter and even proactively schedule maintenance activities. The operator can also set multiple alarm points to represent maintenance requirements and shut down alarms. Finally, data from the DCS system is invaluable during failure investigation to help understand the application conditions leading up to the failure and narrow down the potential causes of the failure.

## **CONCLUSIONS**

As Arrangement 3 seals become more common in industry, there is a need to provide more dual pressurized liquid sealing systems. There are a variety of standardized piping plans to support these needs. While the basic definitions of the dual seal piping plans are well understood, the implications of selection one option over the other is not. The differences in the applications conditions, the seal designs, and the seal support systems can create confusion on selecting the best piping plan. Fortunately, if the user has a better understanding of these options, they can make a more informed decision and ensure a reliable sealing system for their application.

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## **DISCLAIMER**

While the information in this tutorial is believed to be correct, not all information may be suitable or applicable for a specific application. For this reason, the reader assumes the responsibility for the use of this information and should perform a thorough engineering review for their specific application and specific requirements.

## **ACKNOWLEDGEMENTS**

The author would like to Flowserve Corporation for their support in producing this paper. Special thanks go to Ken Lavelle and Scott Svendsen for promoting and supporting the continual advancement of seal technology. Lastly, very special thanks to the Turbomachinery Laboratory and its staff for their efforts in organizing the Symposium and freely sharing this information with industry.